ENVELOP TRANSIENT ANALYSIS: A NEW METHOD FOR THE TRANSIENT AND STEADY STATE ANALYSIS OF MICROWAVE COMMUNICATION CIRCUITS AND SYSTEMS

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ABSTRACT

The two popular and general purpose simulation techniques, Time Domain Integration and Harmonic Balance, do not fulfill the requirement for analysis of microwave communication systems with arbitrary modulated carrier frequency. A new technique is presented, which overcomes this default. A dramatic saving in computer memory space and computation time is obtained with respect to the previous methods.

I - INTRODUCTION

Time domain integration (TDI) (popularized by SPICE [1]) and Harmonic Balance (HB) [2] are at present the most efficient and general purpose techniques for the simulation of microwave communication circuits and systems. Unfornately these techniques do not cover all the spectrum of microwave circuits designers simulation needs.

HB is only suitable for almost periodic steady state analysis. In other words, HB is only effective for simulating circuit response under unmodulated carrier excitation. On the other hand, TDI is only suitable for transient analysis in the base-band, i.e. for the analysis of circuit response to the modulation signal in the absence of carrier. In between, there is no effective and general purpose technique that can conveniently handle transient and steady state analysis of nonlinear circuits for modulated carrier excitation. In the absence of such a technique, the only way to carry communication system analysis under modulated carrier excitation is through the notion of Amplitude Modulation - Phase Modulation (AM-AM, AM-PM) conversion characteristic, which does not effectively take account of nonlinear envelop memory effects [3].

This paper presents an original and general purpose technique termed "*Envelop Transient*", the foundation of which was first initiated in 1993 [4]. This technique efficiently handles the transient and steady state analysis of microwave circuits for arbitrary modulated carrier excitation, without excessive computation overhead.

The Envelop Transient (ET) technique considers any signal as a combination of a low frequency dynamic (the envelop or modulation) and a high frequency dynamic (the carrier) which are processed separetely in a way similar to the well known band-pass and analytic signal theory of Gabor [5]. The high frequency dynamic is treated by HB and the low frequency dynamic by TDI. The result is a direct computation of the time varying envelop or modulation of the carrier, with elimination of the main limitations of both HB (due to large number of frequency components) and TDI (due to large ratio carrier over modulation frequeny). Where TDI would need millions of sampling points, ET only needs hundreds of sampling points as the modulation is no more sampled according to the carrier period. Where HB would carry a cumbersome multitone analysis, ET carries only a sequence of simple one tone analysis.

In the following we will briefly describe the principle of the Envelop Transient method and present some amplifier and oscillator examples which show the effectiveness and efficiency of the new method.

II - THE ENVELOP TRANSIENT METHOD

As it is common when establishing microwave circuits equation, let us consider that the circuit is divided in a purely linear and a nonlinear subcircuit. Any circuit equation can then be put in the form below.

$$\begin{cases} X(\omega) = A(\omega)Y(\omega) \quad + \quad B(\omega)G(\omega) \\ -\infty < \omega < \infty \\ y(t) = f(x(t)) \end{cases} \tag{1}$$

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where $X(\omega)$, $Y(\omega)$ and $G(\omega)$ are respectively the spectrum of the state variables $x(t)$, the electrical variables at the nonlinear subcircuit ports $y(t)$ and the driving sources $g(t)$. $y(t)=f(x(t))$ being the intrinsic characteristic of the nonlinear subcircuit, and $A(\omega)$, $B(\omega)$ the transfert functions characterizing the linear subcircuit.

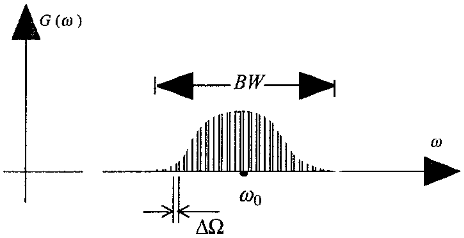


Fig.1 Band-pass signal

If we consider a modulated carrier driving signal as depicted in Fig.1, then every signal $z(t)$ in the circuit has to be written as follows

$$\begin{cases} z(t) = \sum_{k=-N}^{k=N} \hat{Z}_k(t) e^{jk\omega_0 t} \\ \hat{Z}_k(t) = \frac{1}{2\pi} \int_{-BW/2}^{BW/2} \hat{Z}_k(\Omega) e^{j\Omega t} d\Omega \end{cases} \quad (2)$$

where, $\hat{Z}_k(t)$ is the time varying complex envelop (or modulation) of the kth harmonic of the carrier frequency ω_0, and BW the largest bandwidth of envelops of the carrier harmonics.

In the prospective of carrying Envelop Transient analysis, it is interesting to split signals expression in two time dimensions t_1 and t_2 as below.

$$z(t) \Rightarrow \tilde{z}(t_1,t_2) = \sum_{k=-N}^{N} \hat{Z}_k(t_1) e^{jk\omega_0 t_2} \quad (3)$$

Making use of the signal envelops spectra in eq (1); considering a Taylor series expansion of the transfert functions $A(jk\omega_0 + j\Omega)$ and $B(jk\omega_0 + j\Omega)$ within the modulation band BW; and carrying finally the inverse Fourier transform of the first equation line of (1), on the frequency axis Ω, we obtain the Pth ordrer differential Envelop Transient equation[1] of the form below.

[1] In narrow band applications, a first order expansion (P=1) is usually sufficient to achieve a good accuracy.

$$\begin{cases} \hat{X}_k(t_1) = \alpha_{k,0}\hat{Y}_k(t_1) + \beta_{k,0}\hat{G}_k(t_1) + \\ \sum_{p=1}^{P} \alpha_{k,p} \frac{d^P \hat{Y}_k(t_1)}{dt_1^P} + \sum_{p=1}^{P} \beta_{k,p} \frac{d^P \hat{G}_k(t_1)}{dt_1^P} \\ -N \le k \le N \\ \tilde{y}(t_1,t_2) = f(\tilde{x}(t_1,t_2)) \end{cases} \quad (4)$$

We see that for a fixed value of t_1, eq (4) is the well known piece-wise Harmonic Balance equation [2], which makes it possible to compute the time varying complex envelops $\hat{X}_k(t_1)$ of the response, by integrating as in SPICE, the differential equation (4) from the time origin to a desired value $t_{1,max}$ or till the transient dies out. Every envelop time step, a HB analysis is carried, as illustrated in Fig.2.

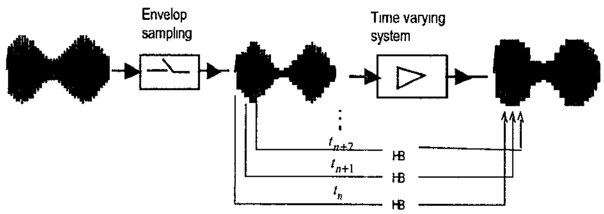


Fig.2 Envelop Transient principle

For presentation clarity of this summary, we have limited ourselves to the case of a single and constant carrier frequency. The above developments can however be carried as well with a time varying carrier frequency, making it possible to consider oscillator and frequency (de)modulation analysis. It is also possible to consider simulation of time varying systems through the notion of Zadeh immittance, making it possible to simulate Doppler circuits. We could also consider a convolution form of the Envelop Transient equation. These enhanced developments will be the subject of an extended version of the paper.

III APPLICATION EXAMPLES

III.1 Microwave amplifier switch-on transient

The switch-on transient of a typical HMIC amplifier is represented in Fig.3(a); this dies out after 120ns. Computation of this transient with a Time Domain Integration simulator like SPICE needs about 1500 periods of the 13Ghz microwave signal and a total of 24000 time samples. Envelop Transient can however directly sample the transient envelop with a time step of 10ns and needs only 12 time samples to cover all the switch-on transient. The computation time is 5s on a HP9000 series 700, in comparison this is 5min with TDI. Fig.3(b) shows the output waveform reconstitution from Envelop Transient analysis. In this reconstitution, only one carrier period is drawn in each envelop time step, hence we can observe the varying carrier waveform within the envelop. Fig.3(b) is to compare with Fig.3(a) obtained by TDI, the signal envelops agreement is good.

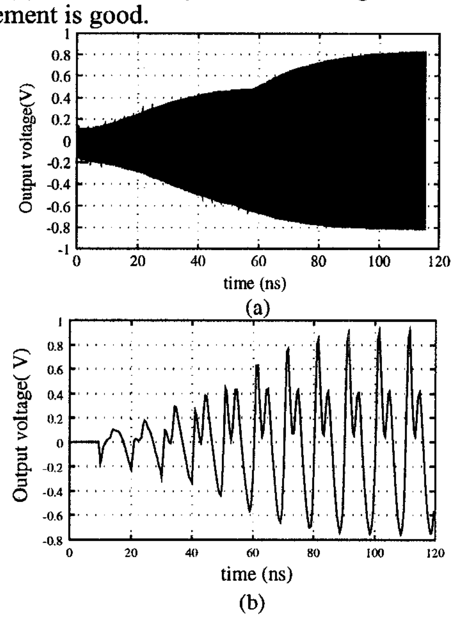
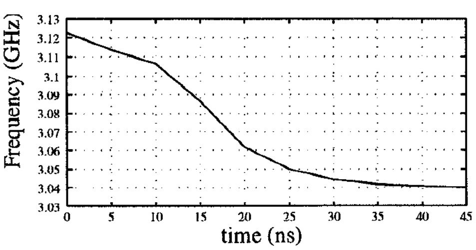


Fig.3 : Microwave amplifier transient analysis
(a) Time domain integration: 1500 carrier period
(b) Envelop Transient : 12 envelop samples

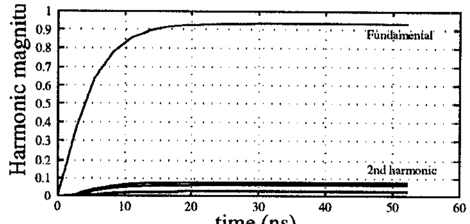
III.2 Oscillator switch-on transient

We have considered the analysis of a MMIC oscillator whose a thorough steady state analysis was presented in [6]. In conjunction with the oscillator analysis techniques presented in [6], Envelop Transient can carry the switch-on transient analysis of this 3GHz oscillator (as well as the steady state analysis), with an envelop time step of 5ns.

FIg. 4(a,b) show time build-up of the oscillator frequency and grow-up of the output voltage harmonics. The oscillation frequency needs about 40ns to get stabilized. The Computation time is 40s.



(a)

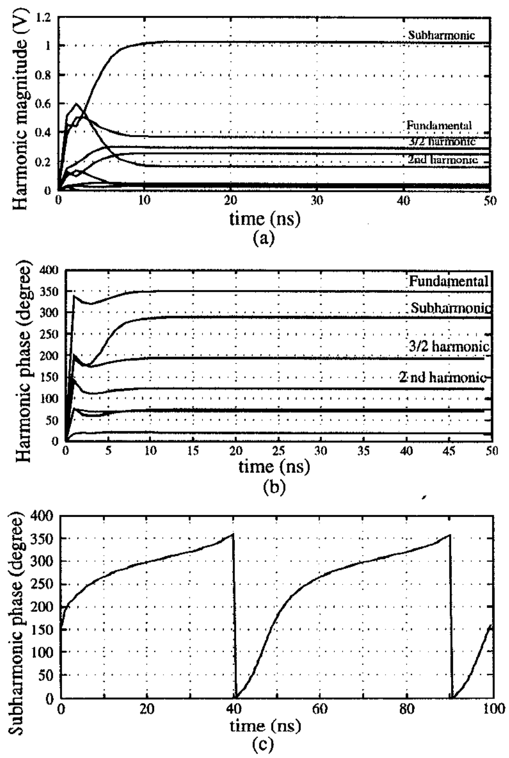


(b)

Fig.4 : Free-running oscillator switch-on transient
(a) Oscillating frequency versus time
(b) Output voltage harmonics magnitude versus tir

III.3 Phase-locked loop acquisition

The oscillator of reference [6] is actually designed as an analog frequency divider by 2, when it is biased at (Vgs=-1.6V, Vds=3V), with a locking range of 5.8 to 6.8GHz. We have computed the divider response for an injection signal of 6GHz and 15dBm. Fig.5(a,b) show the variation of the magnitude and phase of the output voltage (sub)harmonics during the acquisition phase. The loop needs about 15ns before reaching the steady state equilibrium, where the energy is concentrated only at harmonics of half the injection frequency. For an injection frequency slightly outside the locking range, we can see in the phase plot, Fig.4 (c), that the loop does not get locked. The phase is not stabilized on a constant value and the circuit exhibits the well known near synchronization triangular power spectrum, Fig.4(d).



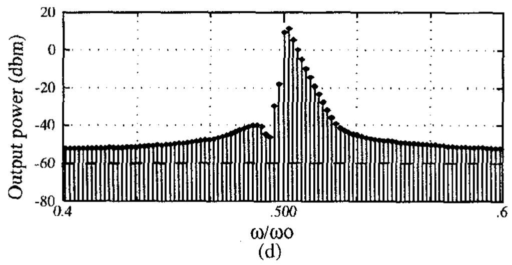


Fig. 5 : Phase locked oscillator transient analysis
(a),(b) Loop acquisition: Harmonics magnitude and phase versus time for 6 GHz input
(c),(d) Near synchronization phase response and power spectrum

III.4 Intermodulation distortion: Noise Power Ratio

To predict inter-channel distortion in a system amplifying multiple modulated frequency carrier, third order intermodulation may not be sufficient. It is therefore necessary to consider more complex intermodulation figures such as the **Noise Power Ratio**, which is the ratio of the intermodulation power falling into a given channel to the total system power. This can be done by considering excitation of the system by a pseudo white noise and band-pass signal of the form depicted in Fig.5(a). Envelop Transient can efficiently carry this type of simulation. Fig.5(b) shows the output spectrum of the amplifier of example 1 to a test signal of 15dBm total power, where we may see intermodulation contribution to the initially off middle channel. The computation time is 5min on a HP9000 series 700.

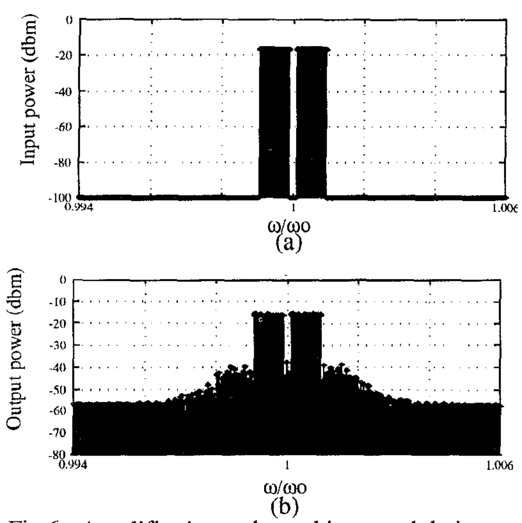


Fig.6 : Amplifier inter-channel intermodulation distortion analysis
(a) Input spectrum, (b) output spectrum

IV CONCLUSION

A new general purpose simulation technique for the transient and steady state analysis of microwave communication systems has been presented, which is a "compound" of the well known Harmonic Balance and Time Domain Integration techniques. The new technique discards the individual limitations of Harmonic Balance and Time Domain Integration, and makes it possible to carry accurately and with reasonable computer simulation time and memory occupation, the analysis of communication systems with arbitrary modulated carrier signals. Typical application examples have been presented, showing the efficiency of the method.

Acknowledgements

This work has been supported by the C.N.E.S: Centre National d'Etudes Spatiales France. The authors would like to thank J. Sombrin from C.N.E.S for its significant aid to carry out this subject. They also acknowledge all the members of their team: "Nonlinear Microwave Circuits" for their contributions.

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